Azimuthal Anisotropy of Charged and Identified High p_T Hadrons in Au+Au Collisions at RHIC

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We report new results on $v_2(p_T)$ for Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV for charged hadrons, pions, kaons, (anti)protons, K_s^0, and Λ. The analysis is extended to $p_T = 12$ GeV/c for charged hadrons and $p_T = 4$ GeV/c for identified particles. A comparison of the azimuthal anisotropy of charged hadrons measured at $\sqrt{s_{NN}}$=130 and 200 GeV is presented. The p_T-dependence of baryon versus meson elliptic flow is discussed.

1. INTRODUCTION

QCD calculations predict that high energy partons traversing nuclear matter lose energy through induced gluon radiation [1,2]. Recent measurements of inclusive charged hadron distributions in Au+Au collisions at $\sqrt{s_{NN}}$=130 GeV show a suppression of hadron yields at high p_T in central collisions relative to peripheral collisions and scaled nucleon-nucleon interactions [3–5], consistent with the picture of partonic energy loss in a dense system. The fragmentation products of high energy partons that have propagated through the azimuthally asymmetric system generated by non-central collisions may exhibit azimuthal anisotropy due to energy loss and the azimuthal dependence of the path length [6]. Elliptic flow [7] at $p_T < 2$ GeV/c measured at $\sqrt{s_{NN}}$=130 GeV reaches the values predicted by hydrodynamical models based on the assumption of complete local thermalization [8,9]. At high p_T, azimuthal distributions of charged hadrons exhibit a structure suggestive of fragmentation of hard scattered partons as well as an anisotropy with respect to the reaction plane [10]. The new STAR data on the azimuthal anisotropy parameter v_2 for Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV extend the measurements up to $p_T = 12$ GeV/c and provide important constraints on the underlying mechanisms of high p_T hadron production in nuclear collisions.

2. EXPERIMENT AND ANALYSIS

The main tracking detector in STAR is the Time Projection Chamber (TPC) situated in a solenoidal magnetic field of 0.5 T. The TPC has wide pseudorapidity $|\eta| < 1.3$ and complete azimuthal coverage, with excellent momentum resolution. Charged hadrons are identified by measuring specific energy loss dE/dx for $p_T < 1$ GeV/c. K_s^0 and Λ

are identified via their V^0-decay topology. A Ring Imaging Cherenkov Detector (STAR-RICH) [11], covering $\Delta\phi = 20°$ and $|\eta| < 0.3$ and situated on the exterior of the TPC, extends charged hadron identification to high p_T.

2.7 M minimum-bias triggered Au+Au interactions at $\sqrt{s_{NN}}$=200 GeV were used for this analysis. The minimum-bias data correspond to $94 \pm 3\%$ of the geometric cross section. All tracks used in this analysis passed within 1 cm of primary vertex and had at least 20 measured space points.

The azimuthal anisotropy of an event in momentum space is quantified by the coefficients of the Fourier decomposition of the azimuthal particle distributions, with the second harmonic coefficient v_2 referred to as elliptic flow [12]. v_2 is inferred from the azimuthal particle distribution with respect to the estimated reaction plane orientation, corrected for the reaction plane resolution. The track selection and calculation of the reaction plane are described in [10]. The reaction plane analysis integrates all possible sources of azimuthal correlations, including those unrelated to the orientation of the reaction plane. A four-particle cumulant method [13] for flow measurements reduces non-flow sources (resonance decays, (mini)jets, final state interactions, momentum conservation, etc.) to a negligible level [14].

3. AZIMUTHAL ANISOTROPY OF CHARGED HADRONS

Figure 1 shows the p_T-dependence of v_2 from the reaction plane method and four-particle cumulant method. The new results from the four-particle cumulant method have much higher statistical precision than previously [14] for centralities 5-70%. Similar to the results at 130 GeV [10,14], v_2 rises linearly for $p_T < 1$ GeV/c, but saturates for $p_T > 3$ GeV/c for both methods. The v_2 values obtained from the four-particle cumulant method are 20% lower than those from the reaction plane analysis. This difference is attributed to the non-flow correlations in the reaction plane analysis, and we assign a one-sided 20% systematic uncertainty for the reaction
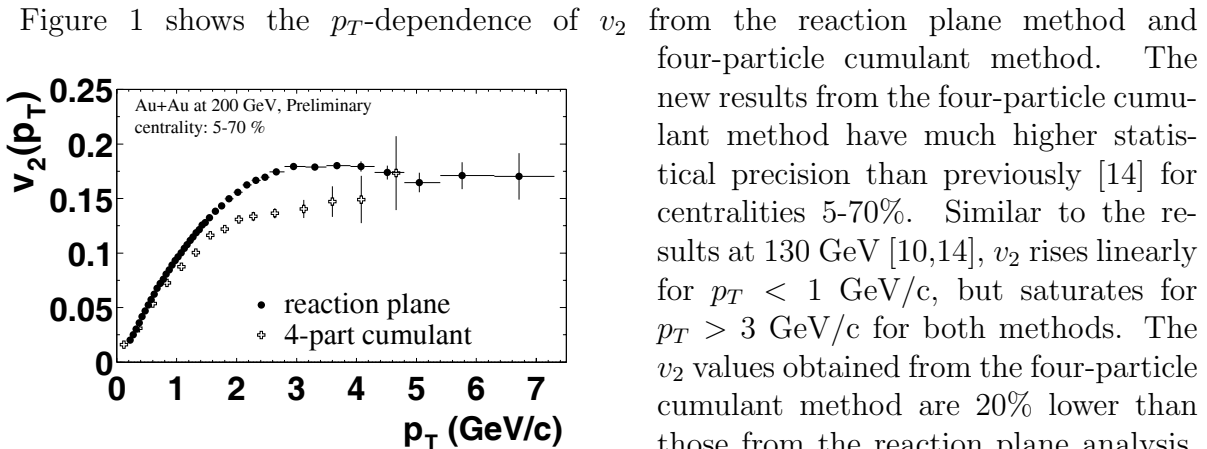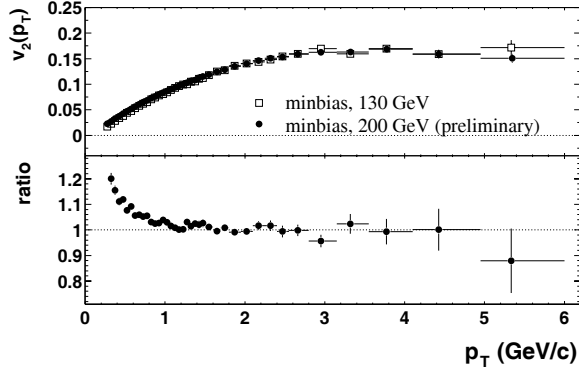

Figure 1: $v_2(p_T)$ of charged hadrons from the reaction plane (circles) and four-particle cumulant method (crosses) for centralities 5-70%.

plane v_2 values presented below.

Figure 2, upper panel, shows $v_2(p_T)$ of charged hadrons obtained with the reaction plane analysis for minimum-bias collisions at 130 and 200 GeV. The functional form of $v_2(p_T)$-dependence is similar at the two energies. Figure 2, lower panel, shows the ratio of v_2 from the 200 GeV and 130 GeV datasets. The elliptic flow is stronger at 200 GeV for $p_T < 1$ GeV/c, suggesting a higher degree of thermalization. In the saturation region at high p_T, the magnitude of the azimuthal anisotropy is the same to within 5%, in contrast to the growth of the inclusive cross section with increasing $\sqrt{s_{NN}}$ [5]. This is an indication of the geometrical origin of the large anisotropies observed in the hard scattering region.

Figure 2. Upper panel: $v_2(p_T)$ of charged particles for minimum-bias collisions at $\sqrt{s_{NN}}$=130 [10] and 200 GeV. Lower panel: ratio of v_2 at 200 GeV to that at 130 GeV.
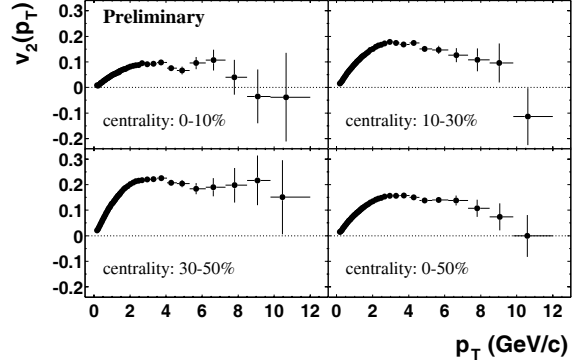
Figure 3. $v_2(p_T)$ of charged particles for different centralities at 200 GeV.

Figure 3 shows the $v_2(p_T)$-dependence for different collision centralities for $p_T < 12$ GeV/c. v_2 remains finite for non-central collisions, exhibiting a decrease from the saturation level at the highest measured p_T for the more central events. It is expected that the azimuthal anisotropy will vanish in the limit of very high p_T. v_2 values measured at $3 < p_T < 6$ GeV/c for a restricted centrality range, corrected for contribution from non-flow effects, are consistent with the maximum expected v_2 from surface emission [16].

4. ELLIPTIC FLOW OF MESONS AND BARYONS

A proposed explanation of the saturation of v_2 at transverse momenta $2 < p_T < 5$ GeV/c is the dominance of baryons in this p_T region described by non-perturbative mechanisms such as baryon junctions or hydro, while pion production is dominated by the quenched pQCD spectra [17]. A qualitatively different $v_2(p_T)$ behavior is therefore predicted for baryons and mesons. Figure 4 compares v_2 of identified charged particles with pure hydrodynamical calculations [15] for $p_T < 3.5$ GeV/c. In Figure 5, a similar comparison is presented for K_s^0 and Λ. At $p_T < 1$ GeV/c, the hydro calculations describe the mass dependence of the elliptic flow well. At $p_T > 2$ GeV/c, v_2 of baryons may slightly exceed that of mesons [17].

5. CONCLUSIONS

STAR has measured azimuthal anisotropies as a function of centrality in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV of charged hadrons for $p_T < 12$ GeV/c and identified hadrons for $p_T < 4$ GeV/c. The experimental observation of large azimuthal anisotropies at high transverse momenta is the focus of ongoing theoretical investigation. Many different approaches have been attempted to describe the data, such as combining hydrodynamical elliptic flow with perturbative QCD including jet quenching [6], parton cascade [18], minijets [19], and surface emission [16]. A simultaneous quantitative description of all the experimental data on high p_T production at RHIC, including inclusive spectra suppression, saturation of v_2, and disappearance of back-to-back jets in central collisions [20],
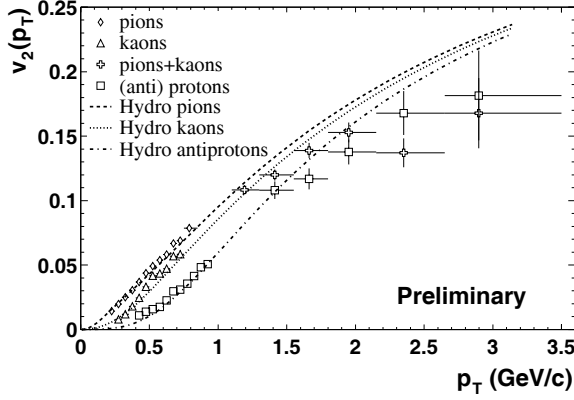
Figure 4. $v_2(p_T)$ of identified charged particles for minimum-bias events at $\sqrt{s_{NN}}$=200 GeV, compared to hydro calculations.
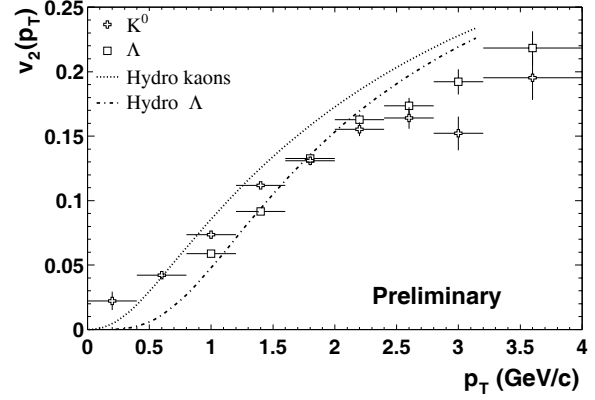
Figure 5. $v_2(p_T)$ of K_s^0 and Λ for minimum-bias events at $\sqrt{s_{NN}}$=200 GeV, compared to hydro calculations.

is needed. However, the data clearly point in the direction of qualitatively new physics phenomena in high p_T particle production in nuclear collisions at RHIC energies.

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